DOI: https://doi.org/10.30837/MMP.2024.078

AUTOMATION SYSTEM FOR PRODUCT IDENTIFICATION BASED ON THE INTERNET OF THINGS TECHNOLOGY

Khrustalova S., Sliusar A., Khrustalev K., Zamirets M.

The purpose of the study is to increase the efficiency of identification of finished products in production. The object of research is the process of product identification using IoT technology. The subject of research is a software tool for product identification using IoT technology. The methods and technologies of product identification are analyzed. The existing commercial solutions for IoT-based product identification systems are reviewed, their structure, technical parameters, functionality and features of their use are investigated, and the advantages and disadvantages of these systems are identified. A structural diagram and algorithm for the operation of the product identification subsystem have been developed. The components of the system are selected, their design and functional features are described, and their technical characteristics are given. The system is implemented as a web application that provides automated collection, processing and transmission of information about identified products for further monitoring and analysis of this data.

With increasing competition and changes in the production environment, new approaches to production management and control are needed. The Industrial Internet of Things (IIoT) allows collecting and processing large amounts of data in real time, which ensures a quick response to changes and optimization of production processes. This study focuses on existing methods, technologies, and systems for automated accounting and identification of finished products, as well as the possibilities of their improvement using IIoT technology.

Product identification systems are complex technological solutions that enable accurate identification and tracking of products at different stages of their life cycle. The main components of such systems are:

a) product identifiers:

1) barcodes – graphic images consisting of black and white stripes of different thicknesses. Each bar or gap between them represents certain information that can be read by a special scanner;

2) RFID tags (Radio Frequency Identification) – tags that use radio waves to transmit information to the reader. They can be active (with a built-in power supply) or passive (powered by the reader’s field);

3) NFC tags (Near Field Communication) – tags that allow the exchange of information over short distances (up to 10 cm), usually used in mobile devices;

4) QR codes – two-dimensional codes that can store more information than barcodes. They are easily read by smartphone cameras and special applications;

b) means of reading identifiers:

1) barcode scanners – devices that use a laser or camera to read information from barcodes;

2) RFID readers – devices that read information from RFID tags using radio waves. They can be stationary or portable;

3) NFC readers – NFC-enabled devices or mobile phones that allow you to read information from NFC tags;

4) cameras for reading QR codes – mobile phones or other devices with a camera that use special applications to recognize QR codes;

c) databases and data management systems:

1) databases – systems for storing information about products, including their identifiers, characteristics, location, etc. They can be local or cloud-based;

2) database management systems (DBMS) – software that provides creation, management and access to databases.

3) application programming interfaces (APIs) – tools for integrating identification systems with other enterprise information systems, such as ERP (Enterprise Resource Planning) or WMS (Warehouse Management System);

d) software for processing identification information:

1) software for reading and processing data – programs that allow reading information from identifiers, transferring it to the database and processing it;

2) analytical tools – software for analyzing the collected data, which allows to receive reports, identify trends and make informed decisions based on the data;

e) network equipment and infrastructure:

1) network routers and switches – devices that connect the components of the identification system to each other and to other enterprise systems;

2) wireless networks (Wi-Fi, Zigbee, Bluetooth) – technologies for data transfer between mobile and stationary components of the system.

In general, product identification systems are based on the integration of hardware and software components that ensure accurate and efficient reading, transmission, storage, and processing of product information. Implementation of such systems allows to increase the accuracy of accounting, reduce the risk of errors, optimize logistics processes and increase the overall efficiency of enterprise management.

Product identification process

The devices that make up the subsystem of interaction with the environment must read the necessary parameters and transmit them for further processing.

In today's world, automatic identification and data capture (AIDC) technology exists to perform such tasks. This term refers to methods of automatically identifying objects, collecting data about them, and transferring it directly to computer systems without human intervention. An object identifier consists of information that allows you to establish an association with this object. This information can be presented in the form of an image, sound or biometric parameters of a person.

The task of automatic identification is to obtain data by processing an image or electromagnetic waves. To collect the data, a converter is used that converts the received information in the form of an image or audio recording into electrical signals that are further processed by a computer. The computer compares the incoming information with an existing database or independently identifies the object.

Data acquisition can be performed using various methods. The following are the existing technologies for automatic object identification and data collection:

– barcode

– radio frequency identification (RFID)

– magnetic stripe;

– optical character recognition (OCR);

– smart cards;

– voice recognition.

Among these technologies, barcodes, radio frequency identification and optical character recognition are widely used to identify food and non-food products.

Optical character recognition is often used when working with documents, but there is also the practice of identifying goods by the image of the packaging. This method is convenient because the user only needs a camera connected to a computer system that will process the image. However, the problem is that it requires a powerful neural model that has been trained on a large number of photos of various products to work correctly. Given the dynamism of the retail market, the emergence of new products, rebranding, or changes in packaging design, the model needs to be constantly updated. This leads to significant time spent on creating and updating the product image dataset and keeping the model up to date.

Product identification is a broad category of labeling that includes functions such as product traceability, brand protection, and how to display information about the product.

The vast majority of food and non-food products produced for retail are labeled in accordance with international standards.

Using Internet of Things (IIoT) technology in product identification systems

The Industrial Internet of Things (IIoT) is a network of interconnected computer systems and connected production facilities with built-in sensors and software for data collection and exchange. These systems enable remote monitoring and control in an automated mode without human intervention.

The use of IIoT technologies in finished goods accounting systems is important for enterprises seeking to improve the efficiency and accuracy of production management. The analysis includes various aspects, such as the use of sensor technologies for accurate data collection, means of ensuring reliable communication, as well as innovative solutions to optimize the management and control of finished goods.

The IIoT technology review covers the study of advanced tools used to connect and control industrial processes. This includes the use of various sensors, data collection and processing tools, and networking technologies for efficient information exchange.

Sensor technologies are used to measure parameters of production processes, such as temperature, pressure, humidity, etc. This data provides accurate and timely information for management decision-making.

Data collection and processing tools organize and analyze large amounts of information coming from sensors and other sources. Data analysis helps to identify trends, predict production scenarios, and increase the efficiency of production processes.

Network technologies provide communication between all devices and production systems, creating a single structure for data exchange. This includes the use of cloud services, IoT protocols, and other innovative methods of information transfer. Communication technologies, such as 5G, NB-IoT, and Wi-Fi, determine the speed and reliability of data transfer between devices.

Cybersecurity in the context of IIoT is a critical aspect, as the growing number of connected devices requires secure information exchange in industrial networks. Protecting the confidentiality and integrity of data is a key cybersecurity objective. The use of data encryption helps prevent unauthorized access to confidential information. Controlling data integrity helps to avoid changes or loss of important production data. Authentication and authorization play an important role in implementing cybersecurity in the IIoT, allowing you to verify the identity of devices and users and manage access levels to systems and data. Measures to protect against attacks and vulnerabilities are important for the security of IIoT systems. Regular monitoring and analysis of potential threats allows you to respond to possible attacks in a timely manner and prevent their consequences.

Benefits of implementing IIoT in finished product accounting systems:

– real-time monitoring: IIoT technologies allow you to constantly monitor finished products in real time, quickly identify deviations, manage inventory and respond to changes in the production process;

– accuracy and automation of accounting: automated systems based on IIoT ensure high accuracy of finished goods accounting, avoiding errors that occur during manual accounting and providing reliable data;

– optimization of inventory management: IIoT systems allow you to effectively track and manage the level of finished goods inventory, avoid excessive stocks, reduce warehouse maintenance costs and improve production planning;

– product quality assurance: monitoring of product quality parameters using sensors and IIoT tools allows for prompt detection of quality deviations, which facilitates timely intervention and improvement of the quality of finished products;

– cost reduction and optimization of production processes: automation with the help of IIoT technologies simplifies many production operations, which reduces labor costs and optimizes work processes;

– improving data-driven decisions: collecting and analyzing large amounts of data creates productive analytical tools that improve decision-making in the management of finished products;

– ensuring cybersecurity: IIoT technologies can include cybersecurity measures that protect finished goods data from unauthorized access and cyberattacks.

Implementation of IIoT technologies in finished goods accounting systems helps to increase the efficiency and competitiveness of the enterprise.

Figure 1 shows examples of IIoT systems.

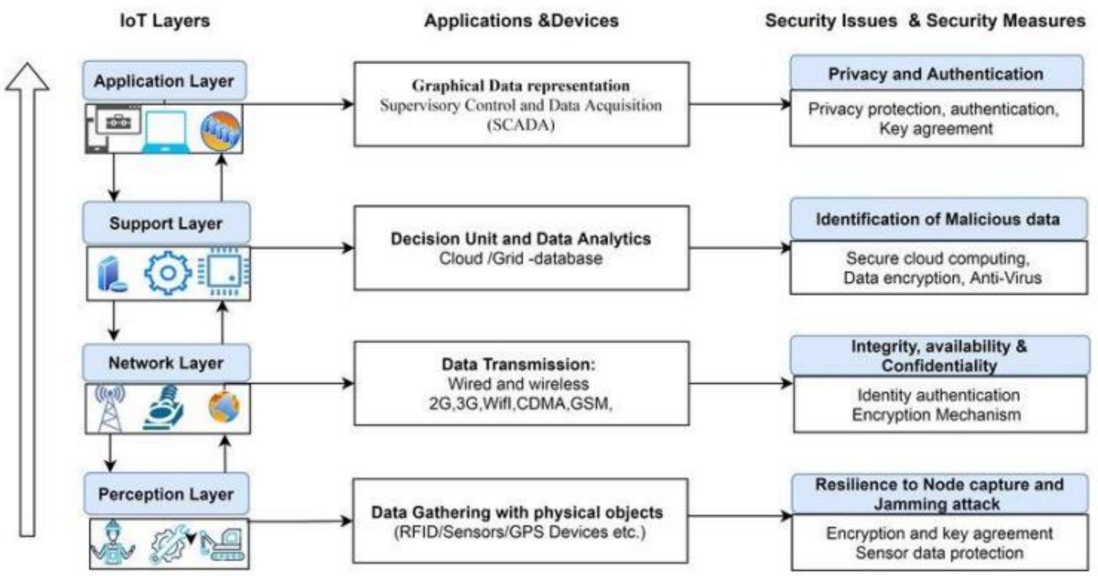

Fig. 1. Examples of IIoT systems

Overview of existing commercial solutions for IIoT-based product identification systems

The world's largest retail chains, such as Wal-Mart Stores Inc., Tesco PLC, and Metro AG, have already recognized the benefits of RFID and are actively implementing it in their distribution centers and warehouses. For example, 40 factories of Ford Motor Co. are equipped with radio identification systems. The British company Tesco has installed more than 4 thousand first-generation readers and 16 thousand antennas to collect data from the radio labels of goods passing through the dock gates of its English warehouses. Tesco also uses radio frequency tags on Gillette razor blades, which allows it to track every product in the warehouse and on the sales floor. If the effectiveness is confirmed, radio frequency tags can be used for many products in the future. This will greatly simplify the work of staff with information and improve customer service. With the help of RFID, it is easy to determine the number of products on the shelves and their expiration date.

The German company Metro started a trial project in November 2005, in which 100 suppliers installed RFID tags with destination data in 10 wholesale stores and 250 warehouses. Metro's first RFID project was aimed at solving the problem of out-of-stock, which can result in an average loss of 8% of retailers' annual revenue, which is about $93 billion a year. The use of RFID at the warehouse level can reduce the number of out-of-stock items on the shelves by 15 to 20%. The project was completed in October 2007, and all deliveries in the 180 German Metro Cash & Carry and Real stores, as well as in the distribution centers and warehouses of Metro Group Logistics (MGL), are fully automated. This was the first example of large-scale practical use of RFID in Europe, which helped to save about $28 million in 2007.

According to a study by the American system integrator Alinean, the use of RFID in warehouses helps prevent errors in deliveries, increases order processing speeds by 20 to 30%, and reduces operating costs by 2–5%, resulting in an increase in annual revenue of 2 to 7%. RFID makes it much easier to track or locate goods in the supply chain, which reduces losses at this stage by 18%.

Simon Langford, Wal-Mart's global RFID strategy manager, estimates that RFID and bar coding will coexist over the next 10–15 years. All the current projects of the world's largest retailers (Wal-Mart, Metro, Target) on the use of RFID technology are limited to the use of tags for labeling pallets, boxes and crates of goods. In particular, in June 2003, Wal-Mart demanded that 100 of its largest suppliers switch to RFID technology for labeling boxes, crates and pallets by 2005. In August 2003, Wal-Mart announced that by 2006 all suppliers would be required to use RFID tags to label boxes, crates, and pallets to ensure a more efficient system of interaction.

In late April, Wal-Mart launched an RFID pilot project in its distribution center and seven centers on the outskirts of Dallas, Texas. This decision is important for the further implementation of this technology. According to Sanford C. Bernstein, after full implementation of RFID technology, Wal-Mart will be able to save up to $8.4 billion annually by reducing manual labor, eliminating sales losses from out-of-stocks, and increasing the efficiency and transparency of its supply chain.

History shows that if Wal-Mart makes a decision, everyone else follows suit. In the 80s, Wal-Mart played a crucial role in the spread of barcoding technology. Although barcodes were standardized in 1973, by 1984 only 15 thousand product manufacturers were using them. After Wal-Mart's intervention, by 1987, 75,000 suppliers were using barcodes.

Existing identification methods and technologies

Barcode identification technology

The barcode was invented in 1949 by Bernard Silver and Norman Woodland, graduate students at the Drexel Institute of Technology. They received a patent for their invention in 1952. However, barcodes were not used in retail until 1967, when barcode scanners began to be introduced in grocery stores in the United States. The principle of coding is that numbers and letters are represented as stripes of different widths. Today, most barcodes are rectangular in shape, while the original design included concentric circles of varying thickness.

Today, barcodes are widely used in various fields. For the average person, they are best known for labeling goods in stores, which speeds up and simplifies the process of delivering goods from the manufacturer through stores to the buyer. But this is not their only use. For example, retail membership cards also use barcodes to identify customers who shop at specific stores. This approach allows for individualized marketing and a better understanding of the shopping pattern from the store's perspective.

The vast majority of existing methods of tracking goods are based on barcode identification. For example, barcodes are used to mark rental cars, airport luggage, waste at nuclear power plants, postal items, etc.

In the medical field, barcodes are widely used. They are used both for patient identification and for keeping medical records (recording each visit to the doctor in a digital format). Even the prescription of medicines can be supported by a barcode and read at the checkout in a pharmacy to display a specific list of medicines.

Barcodes use a one-dimensional coding scheme. The stability of the code is ensured by the height of the bars. That is, if part of the character is damaged, the sequence will still be read correctly. This characteristic is very important, since it is the product packaging that is most often damaged. The code contains information about the manufacturer, product category, and product number. However, it does not contain information about the price, production date, etc. It is only an identifier that requires all the necessary information to be obtained from other data sources, such as a store database or a manufacturer's warehouse.

Types of barcodes

There are many varieties of barcodes, which are divided into two main types: 1D and 2D barcodes. One-dimensional (1D) barcodes are the most common and are usually used on packages and labels. This type of coding is called one-dimensional because the information is stored in one plane – the width of the bars and spaces. The height of the bars does not matter for the information, but only ensures the stability of the code. The longer the message, the longer the barcode. One-dimensional codes are suitable for transmitting a small amount of information, such as a product identification code, which can be used to retrieve all the necessary information from a database. The most common one-dimensional barcode standard in Europe is EAN-13, as shown in Figure 2.

1 234567 890128

Fig. 2. An example of a message in the form of an EAN-13 barcode

It is worth noting that often the decoded information is placed under the barcode for manual entry, for example, if the product packaging is damaged, the cashier can manually enter the numerical code into the cash register system.

Two-dimensional (2D) barcodes are an advanced technology of one-dimensional codes. They are also called matrix or two-dimensional barcodes. The main difference is that the information is stored in two dimensions – vertically and horizontally. Graphically, these codes look like a set of specially ordered dots, squares, circles, or hexagons. A rectangular 2D barcode can contain thousands of characters, which allows you to compactly place a large amount of information. This is convenient for use in logistics structures, where the address, contact information, and names of the recipient and sender of the parcel can be placed in the code [1].

The most common standard for two-dimensional barcodes is the QR code. Due to their popularity, QR codes are supported by standard smartphone cameras, allowing anyone to read the codes and interact with the information. For example, by encoding a website address into a QR code, you can quickly navigate to the site using your smartphone. Or, if the code, as shown in Figure 3, encodes the SSID of a Wi-Fi network and password, the smartphone will try to automatically connect to this network.

```
WIFI:S:<SSID>;T:<WPA|WEP|>;P:<password>;H:<true|false|>;
```

Fig. 3. Format of recording information in a QR code for connecting to Wi-Fi

Figure 4 shows an example of a QR code that contains the necessary information to access a Wi-Fi network with SSID "Test_WiFi" and password "32168421".

Fig. 4. QR code with information for connecting to a Wi-Fi network

Two-dimensional barcodes have a significant advantage over one-dimensional barcodes not only because of the amount of information they can hold. Matrix barcodes are also error-correcting, which allows you to correctly decode information even if the code is partially damaged. In particular, QR codes have built-in error correction using Reed-Solomon codes, which are often used in computer RAM controllers and when writing and reading information from optical disks.

Barcode scanners

To read information from barcodes, special devices are used – barcode scanners. These are optical devices that decode data from printed barcodes and transfer it to a computer or other processing devices. The scanner design includes a light source, a lens, and optical sensors that convert optical signals into electrical signals. Scanners are also equipped with integrated circuit decoders that analyze the barcode image and transmit the decoded data to the output port.

There are many types of barcode scanners, each suitable for specific tasks and applications. For example, scanners can be stationary or portable. Stationary scanners are typically used at cash registers, while portable scanners are convenient for warehouses where employees can move from one item to another to scan. Modern barcode scanners can be classified by the following technologies:

– handheld scanner
– laser scanner
– LED scanner;
– scanner built into the camera;
– omnidirectional scanner.

A handheld scanner looks like a pen with a built-in light source and a photodiode. To read a barcode, you need to slide the pen across all the barcodes at a constant speed. During the scan, the photodiode measures the intensity of the reflected light and determines the width of the bars and the distance between them. The black bars absorb light, and the white bars reflect it, allowing the photodiode to generate a signal based on the level of reflected light. This signal represents the barcode in the form of electrical impulses.

The main advantage of a handheld scanner is its compactness. However, the scanning process is less convenient for large volumes of barcodes, as the user needs to constantly run the pen over the barcode surface to read it correctly.

Laser scanners function in much the same way as pen scanners, with the difference that they use a laser beam as a light source. In addition, they use a mirror or prism to direct the beam after it is reflected from the barcode back to the surface to be read. As with a pen scanner, a photodiode is used to analyze the intensity of the reflected light. With both of these types of scanners, the light emitted changes its brightness rapidly depending on the bars being read, and the use of photodiodes to recognize the code by light intensity is only suitable for pre-known signal modulation.

LED scanners (also known as CCD or LED scanners) use arrays of hundreds of microsensors arranged in a row at the top of the scanner. Each sensor measures the intensity of the light directly in front of it. Each individual sensor is very small in size, but because they are arranged in a row, the output electrical signal is generated by sequentially increasing the voltage across each sensor.

An important feature of LED scanners is that they measure the intensity of light around the white and black bars of the barcode. While the previously discussed technologies measure only the reflected light of a certain frequency generated by the scanner itself.

Camera scanners in mobile devices are considered an advanced method for the average user to scan barcodes. For the most part, this technology allows you to scan two-dimensional barcodes, such as QR or Data Matrix, using a smartphone camera. Among such scanners, it is worth noting those that use high-quality industrial cameras to capture and recognize multiple barcodes simultaneously. All codes that fall into the camera frame are decoded immediately using ImageID technology [2].

Multidirectional barcode scanners use a sequence of straight or curved lines to scan in different directions, forming a star-shaped Lissajous to cross all barcode lines. Most of these scanners use a laser as a light source. Unlike simpler linear scanners, multidirectional scanners can read a barcode from any angle. Typically, these scanners are used at supermarket checkouts, where products are scanned through a glass or sapphire window. These scanners have proven themselves in commercial environments and can range from short-range scanners to industrial conveyor scanners that read information from a distance of several meters [3]. The operation of such a scanner can be seen in Figure 5.

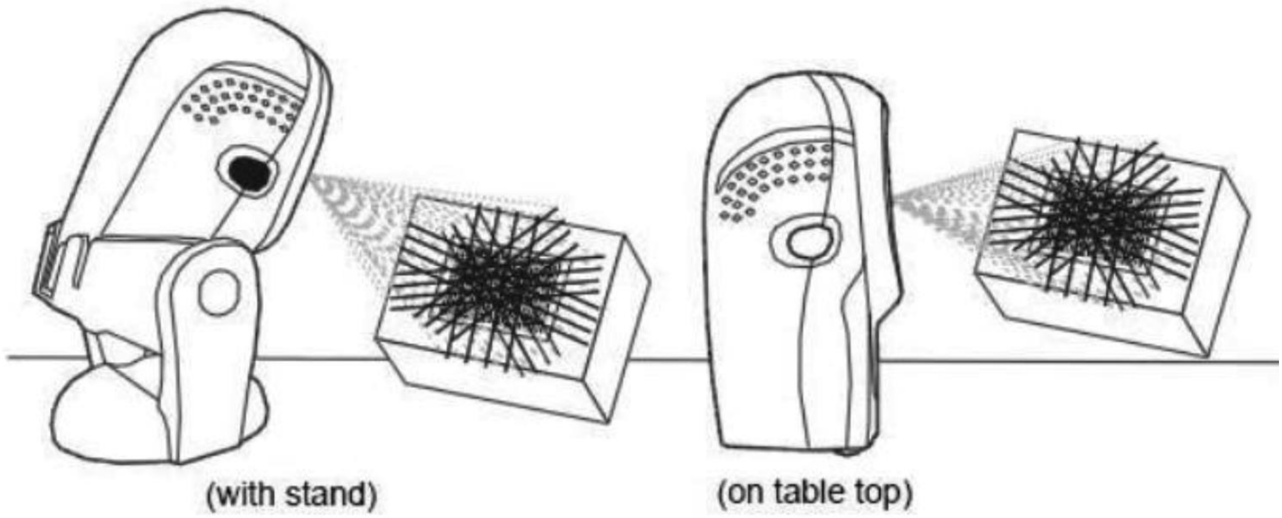

Fig. 5. Beam scattering of a multidirectional scanner

It is this barcode scanning technology that is considered to be the most reliable when codes are damaged, including poor print quality or damage to the barcode surface. Figure 6 shows the types of RFID tags.

Fig. 6. Types of RFID tags

Passive tags do not contain a battery. They use the energy that the electromagnetic wave from the reader induces in the antenna to turn on the chip and transmit data back to the reader. Passive tags reflect energy from the reader or receive and temporarily store energy to generate a tag response to the reader. The tag's antenna absorbs the radio wave energy and directs it to the chip. That is, the larger the antenna area, the more energy it can absorb or catch waves at a greater distance from the radio wave source.

Active tags have their own power source, usually a battery, to run the chips and transmit data to the reader. An active tag allows for weak reception and can generate a high-level signal to transmit back to the reader. The active tag is in sleep mode until it receives a wakeup signal from the reader. As soon as the tag receives the wakeup signal, the storage medium enters the working mode. After the data transaction is complete, the tag goes back to sleep. Since active tags have a battery, they can transmit data without requiring power from the reader. Therefore, they have a much longer reading range than passive tags. On the other hand, because they contain a battery, their lifespan is limited [4].

Semi-active or semi-passive tags, depending on the manufacturer, also have a built-in battery. In this case, the battery is used only for the operation of the chip. Like a passive tag, a semi-active tag uses the energy in the electromagnetic field to wake up the chip and transmit data to the reader. These tags are sometimes called "Battery Assisted Passive".

Each tag has its own tag identifier (TID) programmed into it, which is a unique serial number that is written into the tag by the manufacturer. The tag can also have a memory bank for storing a unique identifier for tracking the product to which the tag will be attached. This is called an electronic product code or EPC.

The EPC is stored in the chip's memory and usually takes up 96 bits of data. The first 8 bits are a header identifying the protocol version. The next 28 bits identify the organization that controls this label (GS1 organization number). The next 24 bits are the identifier of the class to which the product belongs. The last 38 bits are the unique serial number of the tag itself. The last two fields are filled in by the organization that manufactured the tag [5]. The entire code can be used as a key to a database that identifies the item to which the tag is attached.

There is no universal label for all applications. In most cases, it is the tag's antenna that determines the application. Some tags need to work only in a specific frequency range, while others need to deliver the best power when attached to things that are not adapted to wireless communication (e.g. liquids and metals). Antennas can be made of different materials. They can be printed, etched, stamped with conductive ink, or even attached to paper with steam.

RFID tags with memory functions range from simple RO tags to tags with intelligent cryptographic functions. There are tags that have a memory range from a few bytes to about 4 MB of memory. It depends on what type of tag, passive or active, is chosen and what standard was followed in its production.

An RO tag (read-only) has a pre-programmed serial number stored in its memory. The serial number is specified during the manufacture of chips. The user cannot change this serial number or write new data to the tag. When the tag enters the reader's query zone, it sends its serial number and will do so continuously until it leaves the reader's zone. Data communication is unidirectional; data cannot be transferred from the reader to the tag. When using RO tags, the serial number of the tag of the product with which it is associated must be paired with the appropriate software [6].

RW-tag (read-write). This type of label involves writing new information to the label or overwriting existing information. You can write information to the tag only when it is in the read zone. At the same time, of course, you can read information from the tag. RW tags usually have a pre-programmed serial number that cannot be overwritten. But unlike RO tags, RW tags have a memory space where the user can place their own information. The RW tag has limited write cycles depending on the type of memory it uses.

A WORM label (Write Once Read Many) is a label that is in between RO and RW. The name implies that you can create a record only once and then read it many times. When data is written to a label, it is locked, and you can only read information from it [7].

RFID readers

RFID readers are devices that power tags and communicate with them wirelessly and transmit data to software. These devices support bi-directional communication with the devices to which the tags are attached within their range. Readers can perform a large number of tasks, including simple continuous inventory, filtering (searching for a tag according to specified criteria), recording data in specific tags, etc.

RFID tag readers can identify and locate up to 1000 tags per second. The readers can be stationary or mobile and use an integrated antenna to receive data from the tags. Reader chips can be embedded in devices such as handheld readers, smart vending machines, product tracking devices, mobile devices, etc.

Stationary readers must have an antenna that sends energy via radio waves and data with commands to the tags. Since these readers are often used for automation, they can support additional connections to external sensors or to light devices to notify users when a reading is complete. Typically, these devices are connected to a host or network to transmit data from the tags to higher-level applications [8].

Antennas that emit linear electric fields have a long range and high power level that allows the signal to pass through different materials to communicate with the tags. But linear antennas are sensitive to the position of the tags. Depending on the angle or location of the tag, readers with linear polarization antennas may communicate better or worse with the tag.

The choice of antenna is also determined by the distance between the RFID reader and the tag to be read. The reader's antenna can operate either in the near field (short wave range) or in the far field (long wave range). In short-wave systems, the tag is read at a distance of less than 30 cm and uses magnetic communication to transfer energy. Also, in near-field systems, the quality of communication is not affected by the presence of dielectrics such as water or metal in the field.

In readers with far-field antennas, the distance between the tag and the reader exceeds 30 cm and can even reach several tens of meters. Antennas of this type use electromagnetic communication. Thus, dielectrics can degrade the quality of communication between the reader and the tag.

RFID reading distance

The maximum reading distance of a physical tag depends on the power of the RFID reader, the power of the antenna, the actual integrated circuit used in the RFID tag, the material and thickness of the material the tag is covered or protected with, the type of antenna the tag uses, the material to which the tag is attached, and more.

Although the theoretical reading range of RFID tags may be listed in the specification as 5 meters (ideal conditions), in reality, it may be as little as 1 meter if the tag is attached to an object that is on a metal surface surrounded by water and electromagnetic waves (not ideal conditions).

In general, the maximum reading distances for RFID tags are as follows:

– 125 kHz and 134.3 kHz. Low-frequency passive RFID tags – reading distance of 30 cm or less – usually 10 cm, unless a very large tag is used, which can have a reading distance of up to 2 meters when attached to metal;

– 13.56 MHz. High frequency passive RFID tags – maximum reading distance of 1.5 meters – usually less than 1 meter. A single or multi-port reader and special antennas can be used to extend the reading range to a tag with a longer distance or wider RFID reading area. To get more than 1 meter, you need a reader with an RFID output power of more than 1 W;

– 860 MHz to 960 MHz. Ultra-high frequency passive RFID tags – minimum reading distance of more than 1 meter. For example, Gen2 tags can have a reading range of up to 12 meters, but newer generations of chips with a plus antenna increase this distance to more than 15 meters. Gen2 tags can have frequencies of 860 MHz or 902 MHz. Gen2 EPCglobal tags have a frequency range from 860 MHz to 960 MHz. Battery-equipped Gen2 Semiactive tags are semi-passive (semi-active) tags with a reading range of up to 50 meters. Gen2 Semiactive tags are just entering the market;

– 860 MHz to 960 MHz. Integrated circuits of the 3rd and 4th generations. The new generations of integrated circuits (Monza4, Higgs3, and NXP G2XM) are now available in a variety of embedded designs. The use of a different silicon crystal provides up to 40% more sensitivity while reducing RF interference. This means that tags that use the new generation of silicon can have a reading range of more than 16 meters according to FCC regulations for 4 W EIRP [9];

– 433 MHz. Ultra-high-frequency active RFID tags – reading range up to 500 meters;

– 2.45 GHz. Ultra-high frequency active RFID tags – reading range up to 100 meters. There are several different modulations for 2.45 GHz. These active tags can also provide real-time location information.

General description of the system

The system's functioning is based on the fact that there is always information about what products are available at a given time in the store/warehouse, etc. In other words, the system tracks when the products appeared and when they were used, sold, or disposed of.

An important parameter of this system is the suitability of goods for identification. In the previous sections, it was noted that most goods are labeled by manufacturers using barcodes. This method is the cheapest, as it requires only printing a barcode on the package, which has a small area and consists of only black and white stripes of different thicknesses. There are other types of identification, but they require the use of additional devices, which increases the cost of manufacturing the product.

But in terms of usability, barcode identification has certain disadvantages, namely:

– to read a barcode, you need to have direct access to the code itself. Any obstacle will make it impossible to read the code correctly.

– barcodes do not have the ability to record and read additional data other than the identifier;

– barcodes require too much human time and work, as each barcode must be scanned individually;

– barcodes have a low level of security because they can be easily falsified;

– barcodes are easily damaged because they are printed on the outside of product packaging.

Therefore, to increase the degree of automation of the process, it was decided to use an identification tool that does not require human intervention. Radio frequency identification (RFID) was chosen as this technology.

A significant advantage of increasing automation is that to use this method, the user only needs to attach an RFID tag to any type of product. From that moment on, this product can be entered into the accounting system. This makes it possible to add even those products whose packaging does not have a barcode. RFID tag readers react instantly when a tag comes within their range. There is no need to fix the tag in a certain way under the reader, but only to bring it to the minimum required distance.

Any type of product has a certain time of existence from the moment it is produced or purchased to the moment it is disposed of or sold. This is the life cycle of the product in the company's warehouse. As noted, in order to determine which item should be purchased/produced again, it is necessary to track when it was used or disposed of. That is, the system should detect when the life cycle of these products has ended.

To monitor the life cycle, it was proposed to rely on the identifier assigned to the product at the stage of entering the system. For this purpose, it is necessary to identify products at the exit from the warehouse or near it.

In the context of the software and hardware complex being developed as a warehouse product monitoring system, the integration of radio frequency identification technology into the system will allow users to avoid unnecessary operations to add input data to the system. To identify products as recycled/sold, the user only needs to place an RFID reader near the warehouse exit in advance.

However, the use of RFID results in increased costs for the user. Unfortunately, RFID tagging of goods in stores is rarely seen today, as it is not always feasible. Only valuable goods are subject to this method of labeling.

Still, the trend toward replacing barcodes with RFID tags is progressing globally. This year, Kroger, the third largest retailer after Wal-Mart and The Home Depot, introduced a new store format where RFID tags are used instead of barcodes for accounting. Together with Microsoft, they have implemented payment at the checkout via a mobile application using NFC chips [10].

Such events with the participation of world-famous companies in the field of marketing are evidence that in the future the world may abandon the use of barcodes in favor of RFID tags. Therefore, we can say that for today's potential users of the system under development, the inconvenience associated with the need to independently label goods with radio frequency tags is only temporary. In the future, when RFID labeling is provided by retailers or even manufacturers, users will not need to spend time and money on labeling goods themselves.

The software is designed in such a way that it can process data from any of the devices – an RFID scanner or a smartphone. This provides a fairly wide range of alternatives in the context of modern product identification tools. The received identifier will be transmitted to the server via the Internet and processed by the software.

In the developed hardware and software complex, the software part should be responsible for processing information coming from physical devices and presenting it in a user-friendly manner.

The most optimal way to implement this is to create a web application. To identify the user, the web application provides for account registration.

The software and hardware complex is designed for use in premises where it is necessary to automate warehouse logistics. The hardware part of the complex consists of two devices. One of them should be placed at the exit of the warehouse, as it is responsible for recording the fact of disposal/sale of a product unit.

The other device will be used to mark products with radio frequency tags. With its help, the user will record the appearance of a certain RFID tag in the system, and then associate it with a certain product from among those already available in the monitoring system.

Both devices are autonomous units as they have their own power source – a battery that can be charged via the micro-USB interface. This mobile approach makes it easy to place these two devices in any room without the need to provide them with stationary power.

Block diagram of the subsystem and algorithm of user interaction with it

The radio frequency identification subsystem includes the ability to add tags to new products, track tags of existing products, and remove tags of sold/disposed products. Its block diagram is shown in Figure 7.

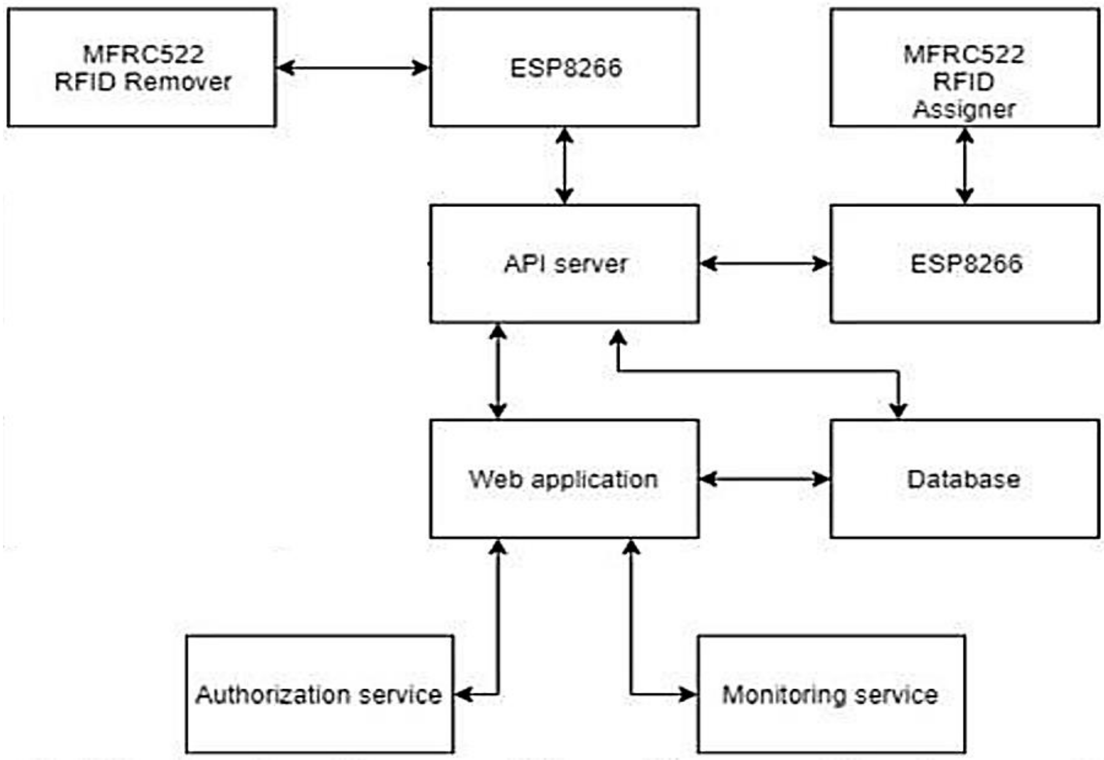

Fig. 7. Block diagram of the product identification subsystem

The location of the tag removal and addition subsystems remains unchanged – the device is located at the entrance and exit of the warehouse. As soon as a tag appears within the range of the RFID reader, it immediately reads it and sends the identifier data to the server for further processing. To solve the problem of the absence of marking goods with radio frequency tags, a similar device is used – an RFID tag reader. The main task of this device is to register an RFID tag in the system. This requires special sticker tags. Each tag scanned by this device becomes visible to the monitoring system but is not yet tied to a specific product. Such a tag can be called “free”. To bind a tag to a product, the user sticks it on the product packaging. Then, in the web application, the corresponding button is clicked opposite the desired product, linking it to the free label. Now the system knows that the label with a certain identifier is tied to a specific product. Thus, the user can label all available products using the advantages of radio frequency identification.

Implementation of the software part

Description of API methods

The software part of the system provides an open API (application programming interface) for interacting with remote devices and functions as a web server for client applications. An API is an interface or protocol for communication between a client and a server that simplifies client-side software development. This interface has predefined methods and a format for responding to requests to these methods. This means that a developer working on software for hardware devices knows what data and in what format should be sent to the server to get the desired response.

The system’s API is developed using MVC Core and is a dedicated controller that provides the following public methods for interacting with the hardware and the client application:

– GetProduct;
– AddUserProduct;
– AddUnassignedRfid;
– BindUnassignedRfidToUserProduct;
– UserProductToBin;
– UserProductToBinByRfid.

Below is a description of each API method and all the necessary parameters to work with it.

GetProduct. Provides data about the product: its ID, name, and a brief description.

HTTP request: GET /api/get-product.

The URL parameters of the GetProduct method request are shown in Table 1.

Table 1

GetProduct method

code	Type: string
	Description: product barcode

If the request is successful, the response body will look like this in JSON format:

{

success: <bool>, product: {

id: < product ID >, title: < product name > , description: < product description >

}

}

AddUserProduct. Adds a product to the monitoring subsystem for the corresponding user.

HTTP request: POST /api/add-user-product

The URL parameters of the AddUserProduct method request are shown in Table 2.

Table 2

AddUserProduct method

userId	Type: string
	Description: user ID
	Type: int
	Description: product identifier
	Type: int
	Description: number of product units

If the request is successful, the response body will look like this in JSON format:

{success: true }

AddUnassignedRfid. Adds a free RFID tag to the system. In this state, the tag waits until the user assigns it to a specific product through the web application interface.

HTTP request: POST /api/add-unassigned-rfid.

The URL parameters of the AddUnassignedRfid method request are shown in Table 3.

Table 3

AddUnassignedRfid method

rfid	Type: string
	Description: RFID tag identifier
	Type: string
	Description: user ID

If the request is successful, the response body will look like this in JSON format:

{success: true }

BindUnassignedRfidToUserProduct. Binds a free label to an existing product in the monitoring subsystem for the current user. The corresponding record is added to the database

HTTP request: POST /api/bind-unassigned-rfid-to-user-product.

The URL parameters of the BindUnassignedRfidToUserProduct method request are shown in Table 4.

Table 4

BindUnassignedRfidToUserProduct method

userProductId	Type: int
	Description: identifier of the record in the monitoring subsystem to which the RFID tag will be attached

If the request is successful, the response body will look like this in JSON format:

{success: true, message: "RFID tag successfully attached to product"}

UserProductToBin. Removes a certain number of products associated with a certain user from the monitoring system. If there are no more such products (all units have been disposed of/sold), the record is completely deleted from the database.

HTTP request: POST /api/user-product-to-bin.

The URL parameters of the UserProductToBin method request are shown in Table 5.

Table 5

UserProductToBin method

userId	Type: string
	Description: user identifier
	Type: int
	Description: product identifier
quantity	Type: int
	Description: number of product units

If the request is successful, the response body will look like this in JSON format:

{success: true }

UserProductToBinByRfid. Performs the same actions as the UserProductToBin method. The search criterion for finding a record to delete is another record that links an RFID tag and a product. This record is located by the tag ID passed to the request. After the item is successfully removed from monitoring for the current user, the record linking the RFID tag and the item is deleted from the database. The RFID tag with the corresponding ID can be used again to link to another item.

HTTP request: POST /api/user-product-to-bin-by-rfid.

The URL parameters of the UserProductToBinByRfid method request are shown in Table 6.

Table 6

UserProductToBinByRfid method

rfid	Type: string
	Description: RFID tag identifier

If the request is successful, the response body will look like this in JSON format:

{success: true }

Using the above methods, the entire business logic of the software and hardware automation complex is implemented. All devices that interact with the goods in one way or another send the received data as parameters to the API methods via the Internet.

Client web application

The client side is presented as a web application consisting of several pages. The main page is the central page and contains links to the pages for adding and deleting products via smartphone, a list of available products in the warehouse, and a button for recording voice commands. The list of goods is generated from the database and displays the goods available in the monitoring subsystem for the current user. Each item in the list includes the name of the product and the number of available units. At the end of each line, there is a functional menu with the following options:

– attach RFID tag: by clicking this option, a free RFID tag will be associated with the selected item and the corresponding record will be added to the database;

– edit: this action redirects the user to the edit page, where you can change the number of available items. This allows you to easily add or delete items in the process of maintaining warehouse accounting;

– delete: this action deletes the record of the selected item from the database for the current user.

The web application supports voice control, which can be more convenient for users compared to scanning barcodes with a smartphone camera. This functionality is especially useful for people with disabilities. For basic interaction with goods, voice control supports two commands: adding and removing goods from the monitoring subsystem. The commands should be pronounced clearly, according to the name of the product displayed in the web application, since the search is carried out by the name, not by the identifier on the package.

To use voice control, press the red button on the home page (Fig. 8). This activates the device's microphone and starts recording the voice command. Next, the user must say the command in the format: action (adding or deleting) and the name of the product to which this action should be applied.

A pop-up window will display the result of command recognition. Since even modern algorithms do not always recognize the Ukrainian language accurately, it is appropriate to confirm the action in this way. If the command was recognized correctly, the corresponding requests are automatically sent to the web application API. The user will see a message about the successful completion of the operation. If the voice command is recognized but does not match the template, the user will receive a notification about this, as well as the text of the recognized command on the main page.

To implement human speech recognition in a web application, the Web Speech API is used. This API consists of two main components: speech synthesis and speech recognition. Speech synthesis is available through the SpeechSynthesis interface, which allows programs to play human language text through built-in speakers. This can be done using different voices and with intonation features, such as emphasizing bold text with intonation.

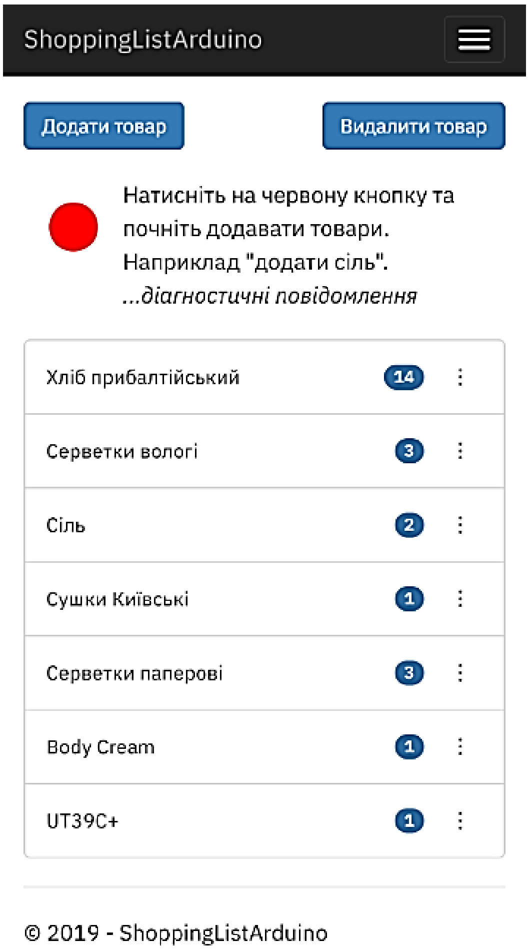

Fig. 8. Home page of the web application

Speech recognition is implemented through the SpeechRecognition interface, which allows you to detect and interpret human speech from audio recordings made by the device's microphone. The SpeechRecognition object is created by the interface constructor, which allows you to recognize the speech context in the recording. The SpeechGrammar interface is a container for a set of grammars that a web application should recognize and is defined using the JSpeech Grammar Format (JSGF).

JSpeech Grammar Format is a cross-platform way to represent grammars for speech recognition. These grammars help speech recognition systems determine what to listen for. In other words, the grammar creates a message template that the speech recognition system is guided by.

For the Chrome browser, the SpeechRecognition interface uses server resources for recognition, meaning that the audio is sent to a web service for processing. Thus, this operation requires an internet connection.

In order to add new products to the internal database of the web application, you need to go to the corresponding page. The link to it is located in the main menu. This page contains a list of all items in the database. A screenshot of this page is shown in Figure 9.

In addition to the list of products already in the database, the page contains a link to the page for adding new products. By clicking on it, the user must fill out a form with three fields (Figure 10). In this form, you must specify the identification code, product name, and description for each field. When the user submits the form, the added product will instantly appear in the updated list of available products in the web application database.

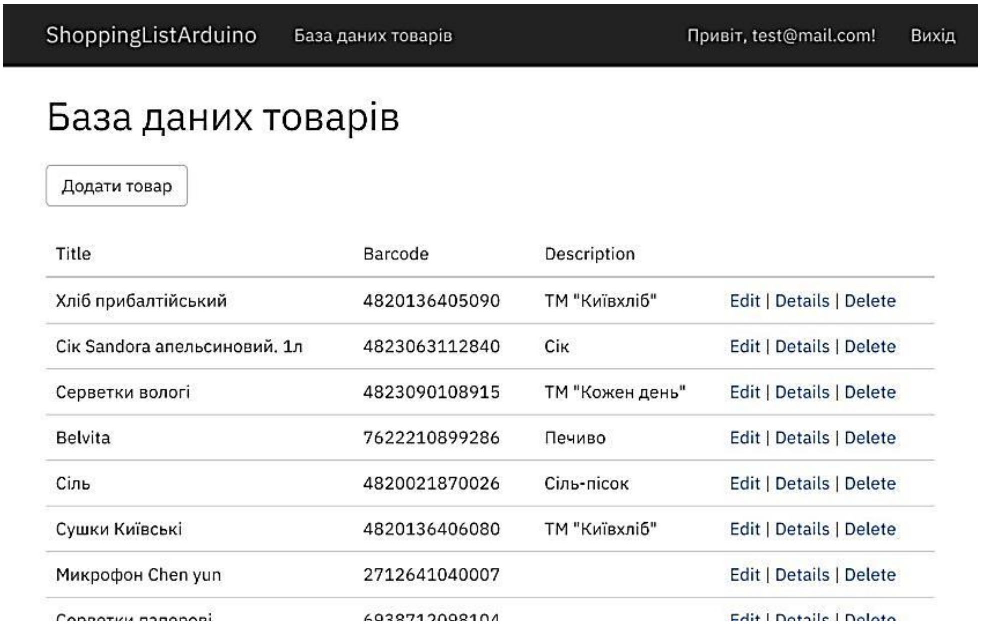

Fig. 9. List of all names in the database

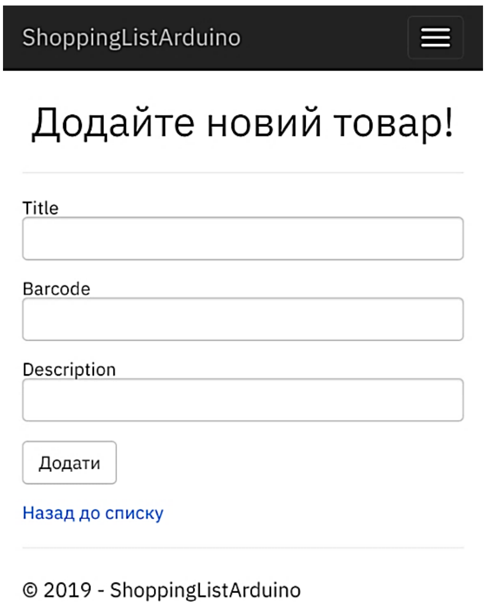

Fig. 10. Form for adding new products to the web application database

Hardware implementation

The hardware consists of two devices that are designed to automate the process of removing products after they have been sold or disposed of. As described above, all of these operations can be performed using a smartphone via a web application. But this will create additional inconvenience, as in this case, it is necessary to have a smartphone at hand at the time of each user action. Let's take a closer look at these devices.

To transfer data via the Internet, the module must connect to the user's Wi-Fi network. Usually, the standard library for working with ESP8266 requires explicit programming of the SSID and password of the access point to which the module connects during initialization. This creates inconveniences for the user, since it is quite difficult to change the firmware of the ESP8266 module every time the access point is changed. To solve this problem, we decided to add a corresponding behavioral template to the program.

At startup, the module scans for available access points within the antenna range. If no SSID and password are stored in the module's memory, the module switches to web server mode and creates its own access point. The user connects to this access point using a mobile phone. Then a web page opens, usually located at http://192.168.4.1.

This page displays all available access points within the module's coverage area. The user selects the desired access point and enters its password. In this way, the user provides the Wi-Fi module with information about the access point to which it is to connect. The access point data is stored in the module's flash memory, and the module automatically reboots. During the next initialization, the module matches the access points stored in the flash memory with those available in real time. After that, the module connects to the network it knows and starts executing its program. The access point configuration page for the ESP8266 module is shown in Figure 11.

To transfer data to the API of the web application program part via the Internet, the ESP8266 Wi-Fi module was selected. However, since the scanner module requires 4 digital pins to communicate via the SPI interface and one digital pin for the RC522 RST module, the standard ESP-01 module is not suitable. Among the various options, the ESP-12E module was chosen, which has more ports, increased flash memory and a more powerful antenna.

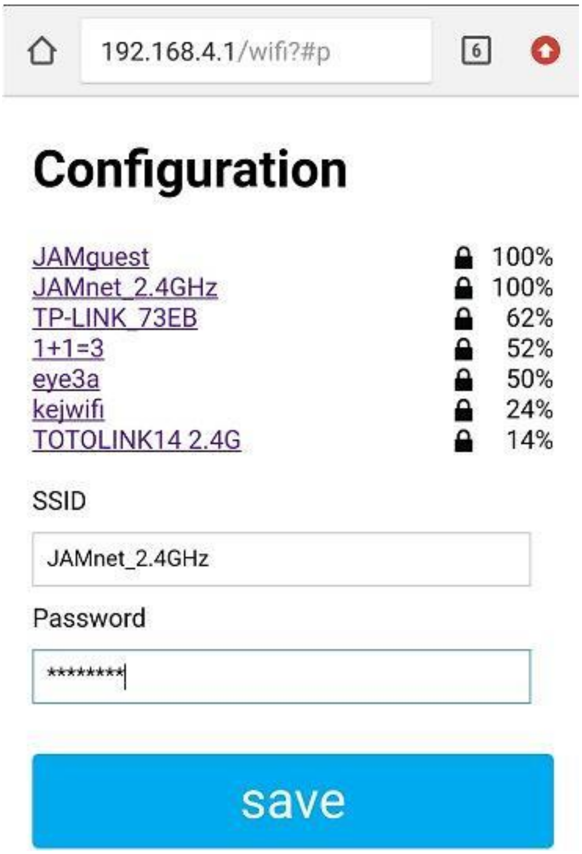

Fig. 11. Access point configuration page

Conclusions

The main goal of the research is to increase the efficiency of identification of finished products in production. The proposed product identification system allows to improve the approaches and methods used to collect, analyze and record data on finished products during movement using IoT technology.

The technological feature that distinguishes the proposed automation system is the support of an alternative, more advanced method of product identification. The Radio Frequency Identification (RFID) method proved to be the most suitable for this role. The identification process includes identifier creation, reading, processing, analysis, and integration of data. The use of the Internet of Things (IIoT) technology significantly expands the capabilities of identification systems by providing continuous monitoring and automation of data processing. In general, the work performed demonstrates the possibility and effectiveness of using IIoT technology to develop product identification systems, which can significantly improve management and accounting processes at the enterprise.

Reference

1. Nevliudov, I., Sliusar, A., Khrustalova, S., Khrustalev, K. and Kosenko, V., (2023). Comparison of the effectiveness of barcoding and RFID technologies in logistics processes. У: 2023 2nd International Conference on Innovative Solutions in Software Engineering (ICISSE), 29 November 2023, Ivano-Frankivsk, Ukraine. Ivano-Frankivsk: Vasyl Stefanyk Precarpathian National University. p. 181–190.
2. Pen-type barcode reader [online]. Bournetocode. [Accessed 26 July 2024]. Access mode: https://www.bournetocode.com/projects/AQA_AS_Theory/pages/img/pen-type-reader.jpg
3. Beam scattering of the Motorola LS9208 multidirectional scanner [online]. Barcodedatalink. [Accessed 26 July 2024]. Access mode: http://www.barcodedatalink.com/media/bakery/images/scan%20omnidirectional%20good%20scan.jpg
4. Hesseldahl, A., (2023). A Hacker's Guide To RFID [online]. Forbes. [Accessed 25 July 2024]. Access mode: http://www.forbes.com/commerce/2004/07/29/cx_ah_0729rfid.html
5. Fedorchuk, A. O. and Fedorchuk, A., (2021). Computerised system for organising access to premises based on RFID technology. [Accessed 5 August 2024]. Bachelor's thesis, Ternopil National Technical University named after Ivan Puluj. Access mode: http://elartu.tntu.edu.ua/handle/lib/35562
6. Hulme, G. and Claburn, T. RFID's Security Challenge [online]. Informationweek. [Accessed 5 August 2024]. Available from: http://www.informationweek.com/story/showArticle.jhtml?articleID=52601030&tid=13690
7. Drozdovskyi, L. I., (2022). Contactless information systems based on RFID technology. MS thesis. Sumy State University. Access mode: https://essuir.sumdu.edu.ua/bitstream-download/123456789/89292/1/Drozdovskiy_mag_rob.pdf [Accessed 5 May 2024].
8. Signals from different types of antennas [online]. Impinj. [Accessed 5 August 2024]. Available: https://www.impinj.com/media/2209/polarization-graphics_ch2.png
9. RFID Card Maximum Read Distance [online]. Uinta6. [Accessed 5 August 2024] Available: https://www.uinta6.k12.wy.us/site/handlers/filedownload.ashx?moduleinstanceid=610&dataid=2363&FileName=Card%20Info.pdf
10. Khrustalova, S. and Vyshvanyuk, S., (2023). Development of a structural diagram of an automation module based on RFID technologies. VIIth International Conference Manufacturing & Mechatronic Systems 2023, 19 October 2023, Khrakiv, Ukraine. Kharkiv: Kharkiv National Univesity of Radio Electronics. p. 22–25.